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Vitalii NAUMOV
Cracow University of Technology
Warszawska 24, 31-155 Krakow, Poland
Corresponding author. E-mail: vnaumov@pk.edu.pl

FORMING DELIVERY ROUTES WHILE PROCESSING THE STOCHASTIC FLOW OF REQUESTS FOR FORWARDING SERVICES

Summary. Formation of rational delivery routes is the main way to increase the effectiveness of client services for freight forwarding companies. The main part of the requests for transport services comes from occasional (non-constant) clients. The set of those requests forms a stochastic flow. For stochastic requests flow, the delivery routes are formed in the process of the requests receipt. Therefore, the standard approaches for merging of requests from multiple clients into routes, based on linear programming techniques, cannot be used in such conditions. An algorithm of formation under the stochastic demand conditions of such delivery routes, which allow servicing of two or more shippers, is proposed in the paper. The author has developed a specialized software to support decisions made by dispatchers of forwarding companies.

1. INTRODUCTION

While making decisions concerning customer service, the transport companies must take into account many factors that determine the main parameters of the technological process and features of its organization. The enterprises of different transport modes have to solve the problem of merging the conflicting interests of shippers, consignees and carriers. The main problem that arises while servicing the transport companies' clients is making unreasonable decisions by servicing organizations, which significantly reduce the effectiveness of the servicing process. The basic directive of solving this problem is to develop and implement optimization tools to support decision-making processes.

One of priorities for contemporary logistics management science is the task of the effective delivery routes development, which is called vehicle routing problem (VRP) [1]. By the process of forming the routes for the delivery of goods, we understand the choice of such sequences of the shippers' detour for the vehicle that provide the optimal value of the efficiency criterion under known parameters of transport demand.

The generally accepted approaches to creating the optimal routes are based on the methods of linear and dynamic programming, combinatorial methods and heuristic analysis [1-3]. The algorithms of the delivery routes scheduling are implemented for situations in which the transportation demand has deterministic nature [2] – for the capacitated VRP with equal demands [4, 5] and VRP with time window constraints [6]. However, the most challenging problem in logistics management is dealing with uncertainty in logistics systems. As is mentioned in [1], customer demand can never be forecasted exactly, travel times will never be certain and machine and vehicles will break down. That is why development of new methods of logistics management, which take into account as much uncertainty as possible, is needed.

For the case of stochastic demand for transport services, which is typical for the contemporary transportation markets, there are proposed models that take into account certain limitations and parameters: metaheuristic model taking into account existing restrictions on loading [7]; the routes development methods based on the model of ant colonies [8]; robust algorithms, addressing uncertainty [9]; multi-agent approach for solving the dynamic VRP [10]; etc.

During the past years, there have appeared new approaches that aim to solve the routing problems in real-time mode, among which the following works should be highlighted: the routing implementation with the consideration of restrictions placed by the drivers' operation modes [11], forming the delivery routes using the adaptive algorithm for searching the nearest arrival point [12], using the iterative search algorithms for harmonization of vehicles and load points functioning processes [13], solving the capacitated vehicle routing problem with stochastic demands applying the simulated annealing algorithm [14], and implementing an integer L-shaped algorithm for the capacitated VRP with stochastic demands [15]. Practical use any of the mentioned routing models offered by contemporary authors envisages development of a specialized software that implements the relevant algorithms.

Existing approaches to forming the different types of cargo delivery routes could be used in the case of deterministic demand parameters. However, the cargo delivery processes in the contemporary transportation market are characterized by the delivery requests flow with dynamically changing parameters. The respective routing techniques should be applied in this case while processing the requests flow [16-20]. It requires making the decisions about delivery routes configuration during short time intervals for the actual demand parameters with the consideration of given rolling stock characteristics.

2. DESCRIPTION OF THE MODEL FOR THE DELIVERY ROUTES FORMATION

Solving the problem of the delivery routes forming for the dynamically changing set of requests requires the definition of the efficiency criteria for the choice of optimal or near-optimal route configurations, mathematical formulation of the problem for the delivery routes formation, and the appropriate software implementation of the algorithms for the routes forming.

The results of the preliminary studies allow us to suggest that as an efficiency criterion of the servicing process for the contemporary transport and forwarding companies, it is appropriate to use the service level coefficient R – a ratio of the serviced requests number to the total number of received requests ($R \to 1$). As a criterion for evaluation of formed routes, the dynamic coefficient of the vehicle capacity utilization γ_d ($\gamma_d \to 1$) could be used.

The process of making the decision on forming delivery routes is being made after the next request arrives on the basis of available information about the requests received earlier. Thus, an algorithm for forming the delivery routes should be iterative, where the identifier of the next iteration beginning is the time moment t_i when the next request appears in the database.

For the newly received request, on the basis of information on requests received earlier, the paired request is selected. It is obvious that the best variant for the pair of request, formed in a route, would be such a case when $\gamma_d^t = 1{,}0$. If for the requests, contained in a database at the moment t_i, such an optimal pair was not found, then the searching procedure should be continued, iteratively decreasing a value of γ_d^t to its low bound γ_d^*.

In general form, the described approach for solving the problem of routing under conditions of the dynamically changing database is presented in Fig. 1.

In the presented algorithm, as an input value (the procedure argument), we use the request r_i on transport services, which was received at the moment t_i; it is also assumed that the information about all the requests received earlier and not serviced is known.

The procedure of searching the paired request from the set of not serviced earlier requests begins from the highest value of the capacity utilization dynamic coefficient: $\gamma_d = 1$. Search of the pair r_i^* is implemented in a special function, the parameters of which are the analyzed request r_i and the given level γ_d. In case the pair was found, the algorithm returns to the formed route $\rho_i = \{r_i, r_i^*\}$, containing the current request and the paired one. If the pair was not found, the allowable value of the capacity utilization dynamic coefficient is decreased on the specified value δ_γ:

$$\gamma'_d = \gamma_d - \delta_\gamma, \tag{1}$$

then the procedure of the pair search is implemented for the current request and the new, smaller value of the coefficient γ'_d.

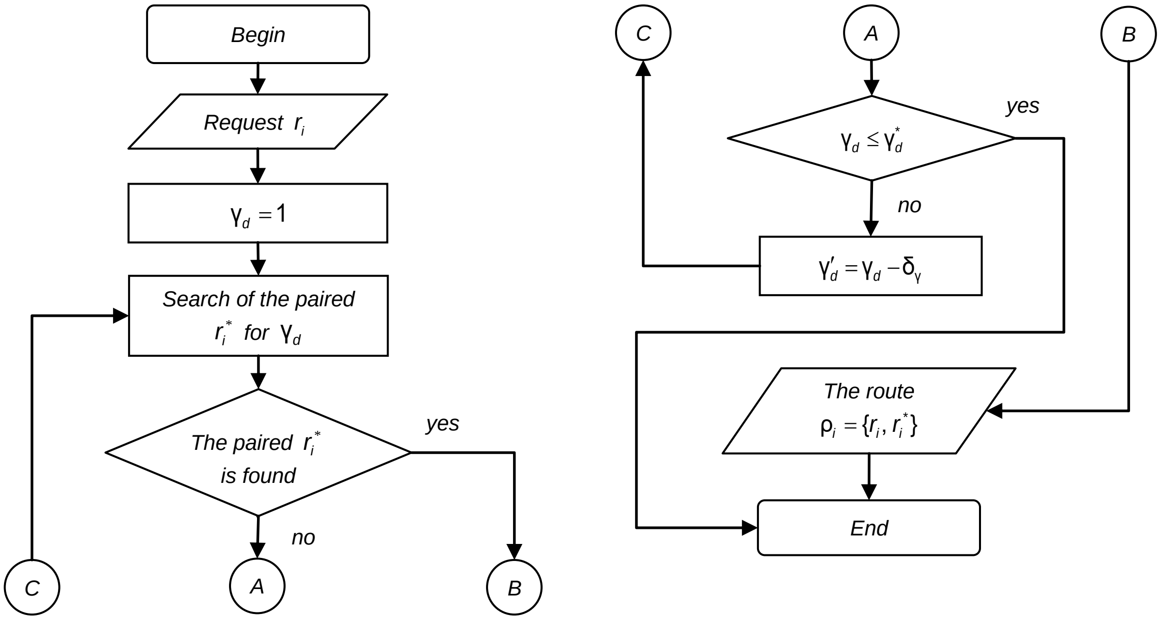

Fig. 1. Algorithm of the method for formation of the delivery routes under the conditions of dynamically changing requests database

This step is repeated until such a route is formed, which is characterized by the γ'_d value of the capacity utilization dynamic coefficient, or the critical value γ_d^* of the coefficient is achieved, meaning that formation of the route for the request servicing is economically inexpedient. In such a manner, the algorithm considers the constraints on the delivery routes effectiveness.

3. IMPLEMENTATION OF THE ALGORITHM SOLVING THE PROBLEM

The algorithm of the proposed heuristic approach for forming the delivery routes under conditions of dynamically changing database was implemented using the PHP programming language (the basic code is available at https://www.academia.edu/25264435).

In the proposed program implementation, the search of the paired request in a set of not serviced previously requests is performed by iterative functions $pair(\$idx)$ and $circ\_pair(\$idx,\$gamma)$. The $pair(\$idx)$ function for the request in a flow with an index $\$idx$ performs the search of the paired request in the set of received earlier requests in the case of pendulum route with the loaded reverse run for the deliveries of the first class cargo. The $circ\_pair(\$idx,\$gamma)$ function for the request in a flow with the $\$idx$ index allows to determine the paired request from the set of requests that were received earlier and were not serviced, under the condition that the *$gamma* parameter of the function is not greater than the dynamic coefficient of the vehicle's capacity utilization for the formed route. The $pair(\$idx)$ and $circ\_pair(\$idx,\$gamma)$ return an index of the paired request an a flow of consecutive requests, if such a request was found, or the value –1, if the paired request was not found.

An algorithm of the $pair(\$idx)$ function is presented in Fig. 2.

At the stage of initialization of auxiliary variables, the $pair(\$idx)$ function algorithm assigns the value –1 to the $pair$ variable, which is used to store an index of the paired request, and if such a request is found, and the value 0 to the variable-counter i, which is used to refer to unprocessed requests received earlier. At the next stage, the algorithm determines an incoming request r_c (the request with the idx index) and the first request r_p from the set of unprocessed requests in a flow (the request with the index $i=0$). The proposed program implementation of the algorithm uses the $input\_reqs$ array to store the requests from the incoming flow.

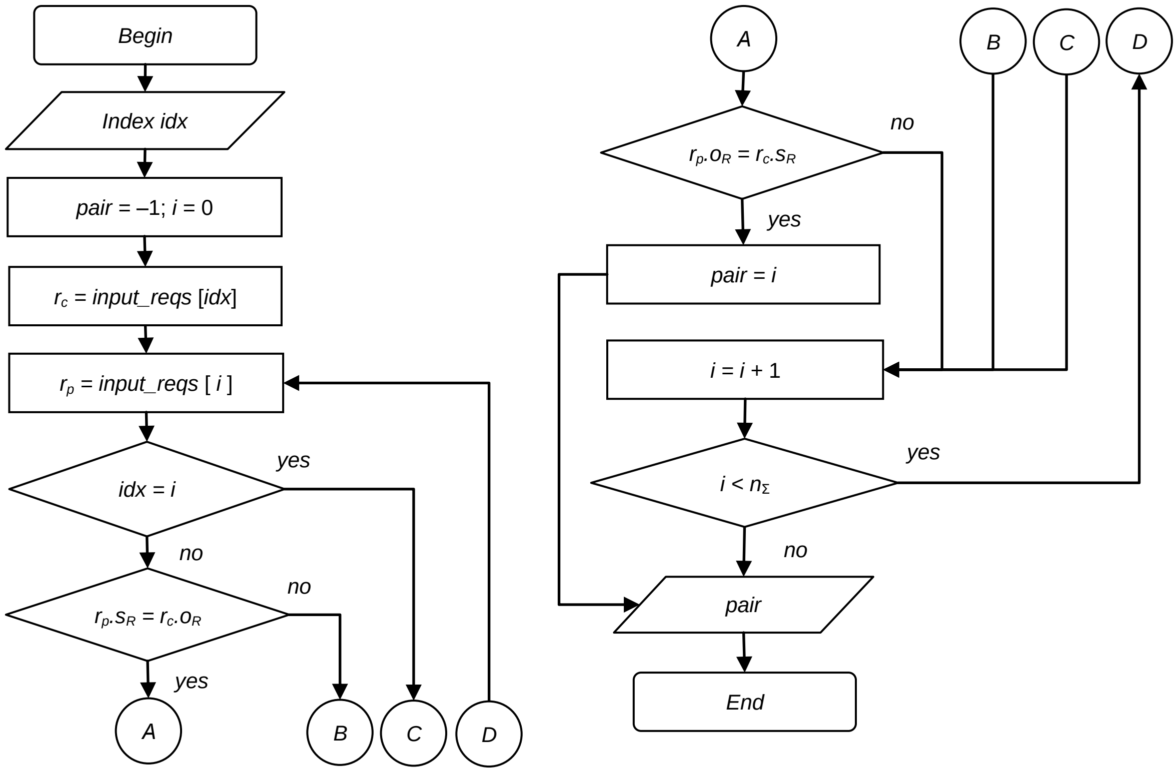

Fig. 2. Algorithm of the $pair(\$idx)$ function

The $pair(\$idx)$ function algorithm defines the r_p request as the paired one, if the following conditions are met:

1) the index of the incoming request r_c is not equal to the index of the request r_p, i.e. in the case of the same request, processing is eliminated: $pair \neq i$;
2) the geographical segment of the consignee o_R of the request r_p coincides with the geographical segment of the consignor s_R for the request r_c: $r_p.o_R = r_c.s_R$;
3) the geographical segment of the consignor s_R of the request r_p coincides with the geographical segment of the consignee o_R for the request r_c: $r_p.s_R = r_c.o_R$.

If all of the described conditions are evaluated to be true, then the i value is assigned to the variable *pair* and is returned by the procedure. If any of the conditions is not satisfied then the value of the counter increases by 1. If not all of the requests from the set of received earlier requests are checked, then the algorithm proceeds to check parity of the next request, otherwise – the algorithm terminates and returns to –1 (this indicates that the paired request was not found).

An algorithm of the $circ\_pair(\$idx, \$gamma)$ function is presented in Fig. 3.

This algorithm corresponds to the structure of the $pair(\$idx)$ function algorithm. The key difference is contained in the block checking the requests parity: the algorithm determines the request r_p as the paired one, if the following conditions are evaluated to be true simultaneously:

1) the index of the incoming request r_c is not equal to the r_p request index (in the case of the same request, comparison is eliminated): similar to the appropriate condition of the $pair(\$idx)$ function;
2) the value of the dynamic coefficient of the vehicle capacity utilization γ_p for the potential route is not less than the specified value $gamma$.

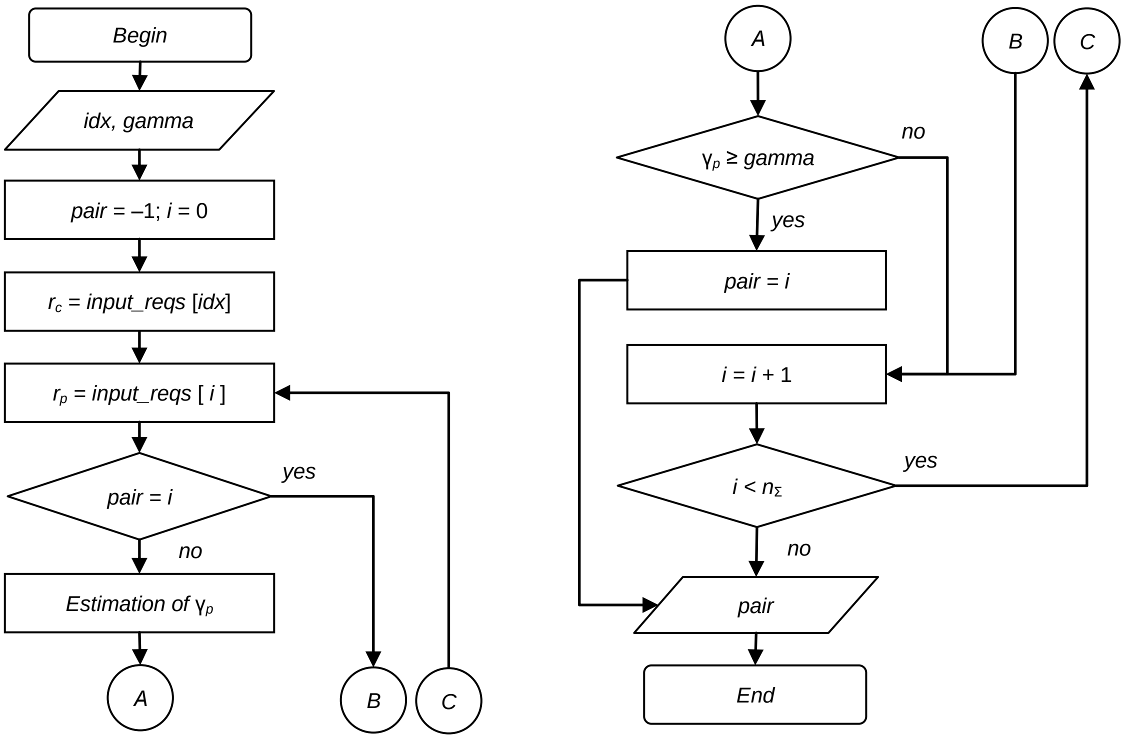

Fig. 3. Algorithm of the $circ\_pair(\$idx, \$gamma)$ function

The procedure of the route forming is considered as a finished one if for the pair of request, the time restriction is completed. In the proposed implementation, this restriction is being considered when the $serve\_req(\$idx, \$pair)$ function of the requests service is called for. The function parameter $\$idx$ refers to the index of the current request r_c and the $\$pair$ parameter – to the index of the paired request obtained as a result of the $pair(\$idx)$ or the $circ\_pair(\$idx, \$gamma)$ functions call.

The $serve\_req(\$idx, \$pair)$ function algorithm considers consequently the following cases for the pair of requests r_c and r_p:

1. The $\$pair$ parameter equals –1: in this case for the request r_c the pair was not found, which means that it could be serviced only using the pendulum route with an empty reverse run. In the proposed algorithm, solving the routing problem with such a request is rejected, because the pendulum route with an empty reverse run is considered as an economically inappropriate one.
2. The $\$pair$ parameter value is not equal to –1: for the request r_c the pair was found, which makes possible forming of the effective delivery route under certain time constraints:

2.1. The incoming request r_c was received later than the paired request r_p:

$$t_r^{(c)} \geq t_r^{(p)}, \tag{2}$$

where: $t_r^{(c)}$, $t_r^{(p)}$ – the reception time of the r_c and r_p requests respectively, h.

2.1.1. The time interval between the requests r_c and r_p exceeds the maximum time waited for the beginning of the paired request servicing: the requests r_c and r_p are not formed into route, but remain in the list of requests, because they could be analyzed further for the lower allowable values of γ_d^*:

$$t_r^{(c)} - t_r^{(p)} \geq t_w^{(p)}, \tag{3}$$

where: $t_w^{(p)}$ – allowable waiting time for the start of the request r_p servicing, h.

2.1.2. The time interval between the requests r_c and r_p is less than allowable waiting time for the start of the paired request servicing: the requests r_c and r_p are formed into the circular (or pendulum with loaded reverse run) route:

$$t_r^{(c)} - t_r^{(p)} < t_w^{(p)}. \tag{4}$$

2.2. The incoming request r_c was received earlier than the paired request r_p:

$$t_r^{(c)} < t_r^{(p)}. \tag{5}$$

2.2.1. The time interval between the requests r_c and r_p exceeds allowable time waited for the beginning of the incoming request servicing: the requests are nor formed into route but remain in the list of requests for further analysis:

$$t_r^{(p)} - t_r^{(c)} \geq t_w^{(c)}, \tag{6}$$

where: $t_w^{(c)}$ – allowable waiting time for the start of the request r_c servicing, h.

2.2.2. The time interval between the requests r_c and r_p is less than allowable waiting time for the start of the request r_c servicing: the requests are formed into route:

$$t_r^{(p)} - t_r^{(c)} < t_w^{(c)}. \tag{7}$$

The algorithms of the described procedures could be considered as a series of calculations for the manual (not automated) methods of the cargo delivery routes forming, but obviously more efficient way of their use is through the program implementation of the proposed algorithms as modules in the specialized information systems of decisions support for transport companies.

4. ESTIMATING THE BOUNDS OF THE PROPOSED ALGORITHM USE

In order to estimate the area of the effective use for the proposed algorithm, the study of dependence of the servicing level on the demand parameters has been conducted. Parameters of demand for freight forwarding services could be defined on the grounds of the logistics portal data, and the method of estimation of the demand parameters is described in the paper [21].

On the basis of the analysis of statistical data accumulated with the use of the logistics portal, the statistical parameters of demand should be defined – the risk relation for ‘time interval between the consecutive requests in a flow, median for the consignments volume, and the expected value of the waiting duration accepted by clients. The mentioned characteristics are the parameters of random variable describing the respective demand characteristics.

Thus, the task of estimation of the demand parameters influencing the efficiency of the routing method could be formulated as the following dependence:

$$R = f\left(m_Q,\ \lambda_I, \mu_T\right) \tag{8}$$

where m_Q – scale parameter of the lognormally distributed random variable of the consignment volume (median); λ_I – scale parameter of the requests' interval exponentially distributed variable (risk relation); μ_T – location parameter of the normally distributed variable of waiting time (the expected value).

Here we perform estimations of the dependence (8) for the following alternative approaches to routing procedures in the bounds of freight forwarding operations:

– the use of the proposed method of the pendulum and circular routes forming;
– forming the delivery routes with the use of the Clarke-Wright method in the real-time mode;
– the mixed variant of routing: at the first step, the delivery routes are being formed; then, for those request, for which the effective delivery routed could not be defined, the servicing with the use of proposed routing procedure is being performed.

For each of the listed alternatives, the simulation experiment has been conducted, where the requests' flow with the mentioned distributions of its parameters had been modelled and the respective routing approach had been applied. As a result of regression analyses of the data obtained from the experiment, the following dependencies were established:

$$R_P = 0{,}077 \cdot \ln\lambda_I + 0{,}097 \cdot \ln\mu_T\,, \tag{9}$$

$$R_D = 0{,}203 \cdot m_Q + 0{,}087 \cdot \ln\lambda_I + 0{,}015 \cdot \ln\mu_T\,, \tag{10}$$

$$R_M = 0{,}138 \cdot m_Q + 0{,}100 \cdot \ln\lambda_I + 0{,}091 \cdot \ln\mu_T\,, \tag{11}$$

where R_P, R_D and R_M represent the servicing level for the proposed method, the Clarke-Wright method and the mixed method, respectively.

The primary analysis of the dependencies (9)–(11) allows us to assert that there exist such values of the demand parameters for which the choice of the most effective routing method from the considered alternatives would be ambiguous, e.g. there would exist areas for the effective use for the considered methods. For the values of the requests' flow $\mu_T = 10\,\text{h}$ and $\lambda_I = 0{,}2\,\text{h}^{-1}$, there exist such values of the consignment volume median, for which the proposed routing procedure would be the most effective way of processing; but also such a range of values for the consignment volume median could be found, where the highest servicing level is being reached by using the mixed processing technology; for the other range of the median values, the Clarke-Wright method implemented in the real time would be the most effective solution (Fig. 4).

In order to determine the bounds of the processing alternative variants, the intersection points of the curves describing the corresponding dependencies $R = f\left(m_Q,\ \lambda_I, \mu_T\right)$ should be estimated. Values of the parameters in the intersection points define the intervals of the demand characteristics, for which the use of the technology results with the highest level of the requests flow processing. The bounds of these intervals could be determined as roots of the following equations:

$$\left[\begin{array}{l} R_P\left(m_Q,\ \lambda_I, \mu_T\right) = R_D\left(m_Q,\ \lambda_I, \mu_T\right), \\ R_P\left(m_Q,\ \lambda_I, \mu_T\right) = R_M\left(m_Q,\ \lambda_I, \mu_T\right), \\ R_M\left(m_Q,\ \lambda_I, \mu_T\right) = R_D\left(m_Q,\ \lambda_I, \mu_T\right). \end{array}\right. \tag{12}$$

Solving the equation $R_P\left(m_Q,\ \lambda_I, \mu_T\right) = R_D\left(m_Q,\ \lambda_I, \mu_T\right)$ with respect to each of the parameters of demand for delivery, we obtain the following expressions for determining the boundaries of the areas of the most efficient use of the processing technologies:

$$\left[\begin{array}{l} m_Q^{PD} = 0{,}401 \cdot \ln\mu_T - 0{,}050 \cdot \ln\lambda_I\,, \\ \lambda_I^{PD} = \exp\left[7{,}952 \cdot \ln\mu_T - 19{,}841 \cdot m_Q\right], \\ \mu_T^{PD} = \exp\left[2{,}495 \cdot m_Q + 0{,}126 \cdot \ln\lambda_I\right], \end{array}\right. \tag{13}$$

where m_Q^{PD}, λ_I^{PD} and μ_T^{PD} represent the effective use boundaries between the proposed technology of requests processing and the variant of servicing with the Clarke-Wright delivery routes for the median of the consignment volume, the risk ratio of the requests interval, and the mean waiting time, respectively, tons, h^{-1} and h.

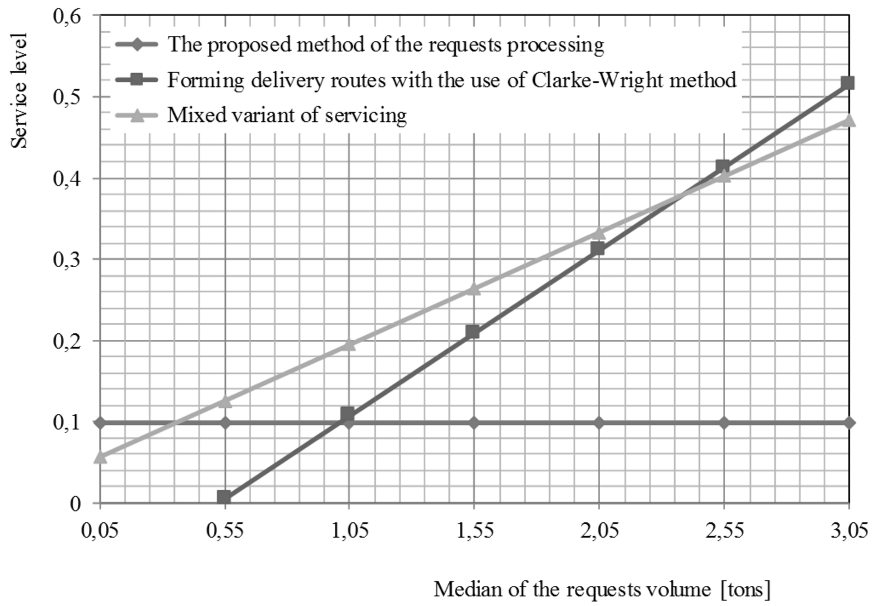

Fig. 4. Dependence of the servicing level on the consignment volume median ($\mu_T = 10$ h, $\lambda_I = 0,2\,h^{-1}$)

On the grounds of the equation $R_P\left(m_Q,\ \lambda_I, \mu_T\right) = R_M\left(m_Q,\ \lambda_I, \mu_T\right)$, we obtain the following expressions for estimation of boundaries of the most effective use of technologies:

$$\begin{cases} m_Q^{PM} = 0{,}039 \cdot \ln \mu_T - 0{,}163 \cdot \ln \lambda_I, \\ \lambda_I^{PM} = \exp\left[0{,}239 \cdot \ln \mu_T - 6{,}123 \cdot m_Q\right], \\ \mu_T^{PM} = \exp\left[25{,}643 \cdot m_Q + 4{,}188 \cdot \ln \lambda_I\right], \end{cases} \tag{14}$$

where m_Q^{PM}, λ_I^{PM} and μ_T^{PM} represent the effective use boundaries between the proposed technology of requests processing and the mixed variant of servicing for the median of the consignment volume, the risk ratio of the requests interval, and the mean waiting time, respectively, tons, h^{-1} and h.

The roots of the equation $R_M\left(m_Q,\ \lambda_I, \mu_T\right) = R_D\left(m_Q,\ \lambda_I, \mu_T\right)$ are the following expressions for estimation of the effective use boundaries:

$$\begin{cases} m_Q^{DM} = 0{,}190 \cdot \ln \mu_T - 1{,}170 \cdot \ln \lambda_I, \\ \lambda_I^{DM} = \exp\left[5{,}276 \cdot m_Q - 6{,}171 \cdot \ln \mu_T\right], \\ \mu_T^{DM} = \exp\left[0{,}855 \cdot m_Q - 0{,}162 \cdot \ln \lambda_I\right], \end{cases} \tag{15}$$

where m_Q^{DM}, λ_I^{DM} and μ_T^{DM} represent the effective use boundaries between the technology of processing based on the Clarke-Wright method and the mixed variant of servicing for the median of the consignment volume, the risk ratio of the requests interval, and the mean waiting time, respectively, tons, h^{-1} and h.

The conducted studies on estimation of boundaries for the most effective use of considered alternative processing technologies allow us to conclude that a preliminary assessment of the appropriateness of the proposed servicing technology use is needed for the given values of the demand parameters. Thus, the choice of the most effective variant of the requests processing technology should be done in the following way:

$$v_{opt} = \arg \max_{i \in \{P,D,M\}} R_i \tag{16}$$

where $\{P,D,M\}$ – a set of alternative variants of the requests processing: P – the variant of servicing on the grounds of the proposed method, D – the variant of servicing with the use of the Clarke-Wright-formed delivery routes, M – the mixed variant of servicing; and R_i – the service level average value for the *i*-th variant of servicing.

It should be mentioned that the set of alternatives for the used processing technology could contain other methods (or algorithms) for the delivery routes forming.

5. CONCLUSIONS

Due to the competitive characteristics of the transport services market and its stochastic nature, there is a strong need for increasing the efficiency of servicing processes provided by forwarding companies to their clients. To achieve the goal of increasing the efficiency of forwarding enterprise, the most important component of the servicing technology is proposed to be improved – the routing process.

The proposed heuristics allow researchers and logistics managers to solve the problem of the circular and pendulum routes formation under conditions of dynamically changing demand (requests database). Program implementation of the described algorithms could be used in decision support information systems for transport and freight forwarding companies.

The conducted studies on detecting the boundaries of the proposed algorithm usability have shown that there are such values of demand parameters when the developed approach could be considered as the most effective techniques of the requests flow processing.

The perspective direction of further studies is the development of procedures for the formation of circular routes with the number of freight owner pairs greater than 2. Such cases usually appear during the small-lot cargo deliveries in urban environments, so the proposed method of the delivery routes forming could be applied in a framework of the city logistics theory.

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